A Simple Tunable Low Pass Active Filter

A fifth order Butterworth filter in an eight-pin chip.

by James Lyman

In experimenting with electronic systems, we often need filters to condition signals we are using. Usually a low pass filter is required to eliminate higher frequency noise, so an active low pass filter is needed having a cutoff frequency the same as the frequency we are trying to work with.

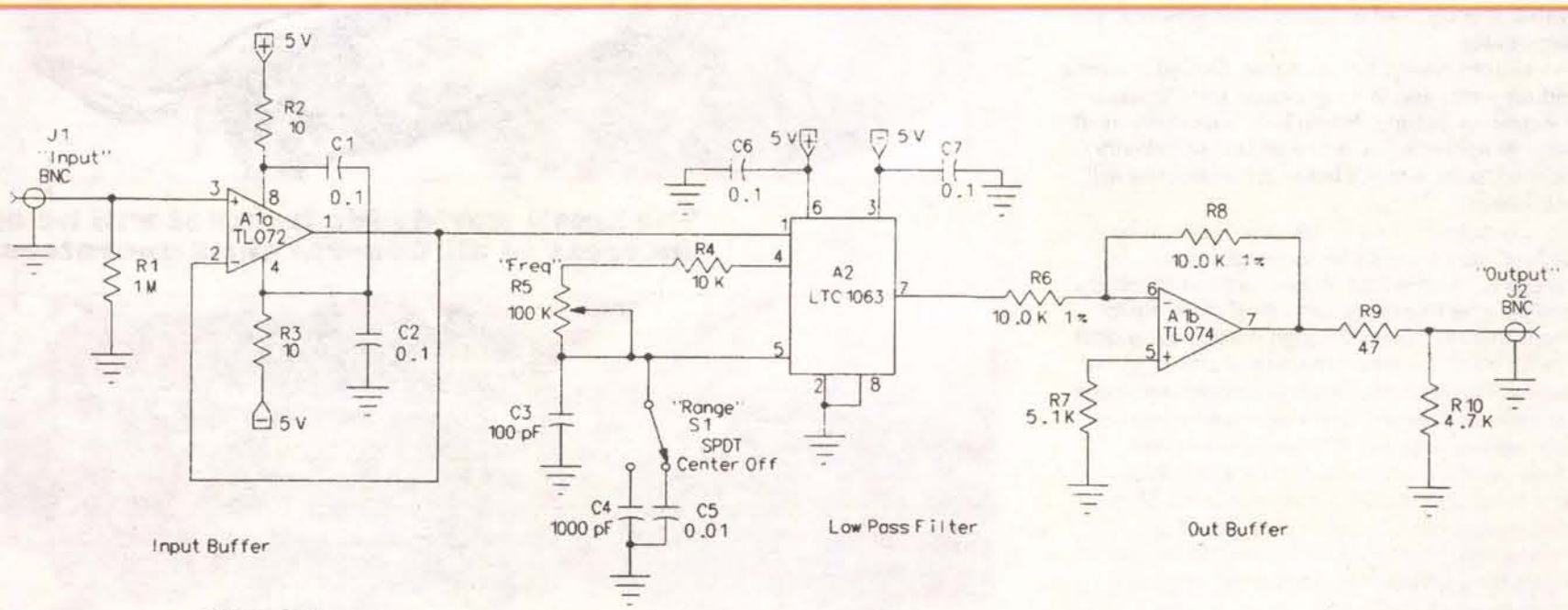
Commercially-tunable filters are an expensive piece of laboratory equipment which most home electronic experimentalists cannot afford — even from the used equipment market.

Consequently, the experimenter needs to design and build a custom low pass active filter for each task. This means a filter is not used unless it's absolutely necessary. But now, a single eight-pin chip gives the experimenter a very effective tunable low pass filter to use over and over.

This chip is Linear Technology's LTC1063 which is a DC Accurate, Clock-Tunable Fifth Order Butterworth Low Pass Filter.

Using a simple input and output buffer, this chip forms the complete filter circuit, including the tuning circuit for cutoff frequency.

As used in this circuit, the tunable filter has a range of 7 to 8,500 Hz which is continuously variable over three switch selected ranges. It accurately passes the DC component of a signal and has wide band noise in the micro volt levels. The distortion plus noise is rated at -80 dB and, being a fifth order filter, its frequency rejection curve is very steep so, if set for a cutoff frequency of say 25 Hz, a 60 Hz signal would be



Last Used	Spares	Not Used
A4	none	none
C9		
J3		
R10		
S1		

Figure 1. Filter Schematic Diagram

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attenuated 40 dB.

The LTC1063 Chip

Linear Technology's LTC1063 is a wonder in a small package. It is a clock tunable filter whose simplicity defies words for allowing the experimenter to easily and quickly design, then build a low pass filter. This monolithic filter is a fifth order filter using switch capacitance technology which, in a very rough and crude way, means it's equivalent to five filters in series. That's what gives this filter such sharp rejection of out of band frequencies.

Being a switch capacitance filter, the designer needs only to provide a digital clock signal which is 100 times the desired cutoff frequency, and this clock signal may be provided externally from another circuit or internally with the RC oscillator built into the chip.

Other than two decoupling capacitors on its power supply, there are no other components required — how can it get any simpler? If the internal oscillator is used, then a resistor and capacitor are selected which gives a clock frequency defined by the product of the resistor and capacitor values. The clock frequency is 100 times the filter's desired cutoff frequency which equals 1/R*C, where R is in ohms and C is in farads. The resistor goes between pins 4 and 5, while the capacitor goes from pin 5 to ground.

So, if you want a low pass filter with a cutoff frequency of, say 120 Hz, then a digital clock of 12 KHz (120 x 100) into pin 5 will give that cutoff frequency without any other components or adjustments. To use the internal oscillator, the frequency of the clock is set by a resistor-capacitor combination equaling approximately 1/RC, so start by selecting either a resistor or capacitor value.

The resistor value should be greater than 10 Kohms and the capacitor greater than 100 pF. Calculate the other component's value with Fclock = 1/RC. So, for a resistor of, say 100 Kohms, the required capacitor value should be:

C = 1/(R * Fclock)
C = 1/(100,000 * 12000)
C = 833.3E-12

Use the nearest standard capacitor value of 820 pF for a calculated cutoff frequency of 122 Hz. If a capacitor is selected, then find the resistor by:

R = 1/(C * Fclock)

Connect the resistor, capacitor, and a split power supply with 0.1 uF decoupling capacitors and the filter is ready to go. The power requirements are between ±2.375 and ±8 volts, but the clock signal is unipolar so, when ±5 volts is used, a standard TTL signal can be used to drive the filter.

The data sheet isn't very clear about input signals greater than the filter's power supply voltages but, if it's just a little over, the chip will instantly be destroyed. The LTC1063 is available from Digi-Key (part number LTC1063CN8-ND) and costs only $10.00 in single quantities. It is usable over a 50 KHz bandwidth and is cascadable for sharper frequency rejection. For a two-volt RMS signal, it has 0.01% THD making it ideal for use with audio circuits.

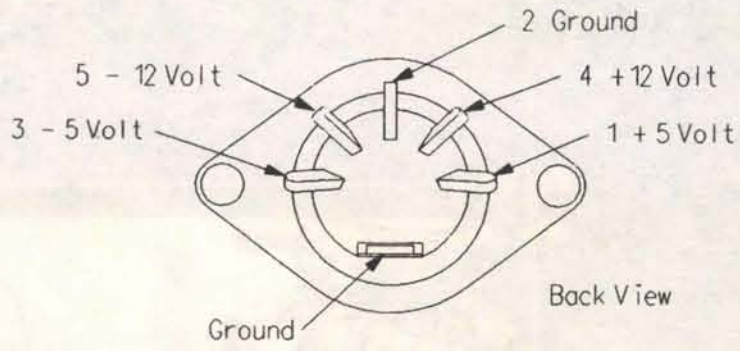

Figure 2. Power Connector Pin Outs

Figure 3. Instrument Setup

The Filter

To use the TLC1063 as a tunable filter, I used its internal oscillator and added a variable resistor with sufficient value to cover one decade of frequency. To further expand the filter's tuning range, I added switch selectable capacitors for overlapping decades of frequency. With three capacitors, the filter is tunable from 7 to 110 Hz, 90 to 1,200 Hz, and 1,000 to 8,500 Hz. Since capacitors often have a wide tolerance, it's best to select capacitors with a capacitor meter or by tack soldering the capacitor in circuit and testing the sweep range.

If you select the "capacitors in circuit" method, start with the lowest value (highest frequency range) and work up in capacitors making sure the next capacitor overlaps the previous one.

You can add additional capacitors — and hence ranges — using a multi-pole rotary switch. Increasing the range entails using smaller values of capacitance, making the circuit more susceptible to influences of parasitic capacitance — a real prob-

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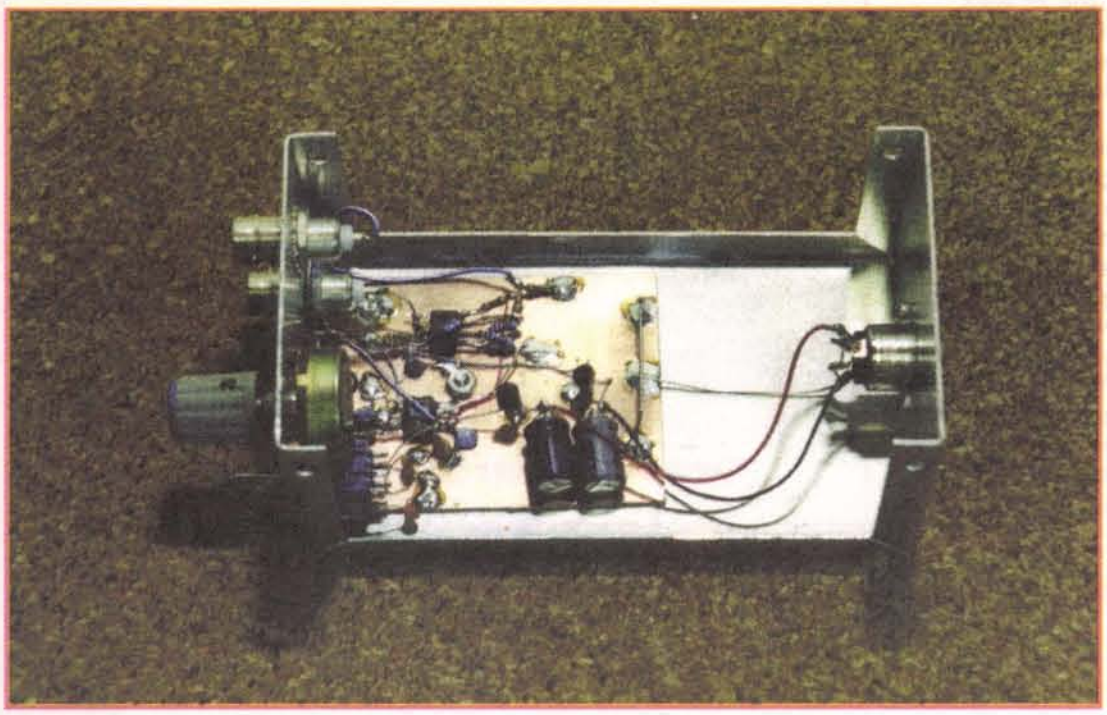

Figure 4. Instrument Interior

lem when a switch is part of the circuit. The data sheet is vague about the minimum resistor value from pins 4 to 5, so you may lose a chip or two in trying to push the frequency too high.

Circuit Description

Both the input and output of the filter is buffered by opamps. The input buffer A1a is a source follower opamp configuration with a very high input impedance and a unity voltage gain.

Resistor R1 (refer to Figure 1, Filter Schematic Diagram) with a value of one megohm serves two functions. This first is to set the filter's input impedance to a standard and constant value. The second is to connect the opamp's input to ground, so if a signal is coupled in by a capacitor, no DC voltage will build up until the amplifier is driven into cutoff.

Resistors R2-R3 and capacitors C1-C2 form a filter network for amplifier A1's power supply. Each resistor-capacitor forms a low pass RC filter for each voltage rail, with C1 between the positive and negative rails for rejection of differential mode noise, and C2 for common mode noise.

This decouple network is commonly used for opamp applications and is recommended over using just capacitors to ground to give superior protection against noise on the power supply.

The output of input buffer A1a goes directly into the filter's input at pin 1. The filter A2 is very sensitive to input over voltages and is easily damaged if it exceeds the power supply's voltage rails. The input buffer serves as protection for over voltage input to the filter since the opamp is very tolerant to over voltage, but its output cannot exceed the power supply rails.

A2 forms the complete fifth order low pass filter whose cutoff frequency is determined solely by a digital square-wave whose frequency is 100 times the filter's cutoff frequency. The internal clock is used in this design so a resistor and capacitor are used between pin 4 (Clock Output) and pin 5 (Clock Input).

To make the filter tunable, a variable resistor R5 is used in series with a fixed resistor R4 that provides the minimum resistance value of 10 Kohms. This resistor combination is between pins 4 and 5 of A2 and the capacitors C3-5 complete the RC timing circuit. To give a wider range of operation, different values of capacitance are switched in by a toggle switch.

The capacitor for the highest range C3 (1 to 10 KHz) is permanently in the circuit with the other two frequency range capacitors C4 and C5 switched in by the SPDT center off switch S1. For the lowest frequency range (10-100 Hz), C5 is switched into the circuit parallel with C3, for the mid range (100 Hz to 1 KHz) C4 is switched in, and for the highest range S1 is in its center off position, so only C3 is in the timing circuit. Varying resistor R5 allows the cutoff frequency to be continuously varied across the range set by the capacitors.

The filter's input is pin 1 of A2 and its output is pin 7. This filter is a true low pass so it will accurately pass the DC component. The filter uses a split rail power supply of five volts and has decoupling capacitors C6 and C7 to ground as recommended by the manufacturer's data sheets.

To isolate the output of filter chip A2, a unity gain buffer amplifier is provided using the second half of opamp A1. The buffer amplifier is an inverting amplifier because — in my application — the filter's output is approaching -180 degrees in phase shift and I wanted to correct this. According to the manufacturer's data sheet, the filter has a constant phase shift of about -20 degrees in the pass band but decreases rapidly as the frequency approaches the cutoff. This is the region I intended to use my filter in, but for applications using the whole pass band a non-inverting buffer may be used. This would be a source follower configuration the same as the input buffer with its input to pin 5 of A1b and pin 6 connected to output pin 7.

So the output of an opamp buffer can drive coax cables, a DC decoupling network is used on the output of the buffer amplifier. Resistors R9 and R10 provide a DC path for opamp A1b's output other than through a coax cable and some unknown load which may be highly reactive, such as a capacitor. Such loads can make an opamp to be unstable creating numerous problems in the opamp's performance, which changes as the load is changed.

Resistors R9 and R10 provide a voltage divider ratio of 0.99 which decreases the output and gives a one percent error but provides the essential DC path to ground. This error is usually sufficiently small to ignore, but for applications requiring higher accuracy, the gain of the buffer amplifier can be adjusted by using a 200 ohm trimmer resistor in series with feedback resistor R8, but remember, a one percent error is usually less than the accuracy of your instruments.

The power supply for the circuit is regulated using two small three-terminal regulators at each rail to give ±5 volts. Since the current requirements for the complete filter circuit are so small, the 100 mA TO-92 style regulators are used with each input having a 470 uF input

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PARTS LIST

Ref. Desg.	Qty.	Nomenclature	Part No.
A1	1	TL072 Dual Bi-FET opamp, eight pin DIP	Note 1
A2	1	LTC1063 Clock-Tunable Fifth Order Butterworth LP Filter	Note 2
A3	1	78L05 +5V, 100 mA, three terminal voltage regulator, TO92	Note 3
A4	1	79L05 -5V, 100 mA, three terminal voltage regulator, TO9	Note 4
C1,2,6,7	4	0.1 uF Monolithic Bypass Capacitor, 25V	
C3	1	100 pF Ceramic Disk Capacitor, 25V	
C4	1	1,000 pF Ceramic Disk Capacitor, 25V	
C5	1	0.01 uF Monolithic Capacitor, 25V	
C8,9	2	470 uF Electrolytic Capacitor, 25V	
J1,2	2	BNC Panel Mount Bulkhead Recept, Solderable	Note 5
J3	1	Five-position DIN Receptacle, panel mount	Note 6
R1	1	1 Mohm Resistor, 5%, 1/4 Watt	
R2,3	2	10 ohm Resistor, 5%, 1/4 Watt	
R4	1	10 Kohm Resistor, 5%, 1/4 Watt	
R5	1	100 Kohm Potentiameter, Linear, Panel Mount	Note 7
R6,8	2	10 Kohm Resistor, 1%, 1/4 Watt	
R7	1	5.1 Kohm Resistor, 5%, 1/4 Watt	
R9	1	47 ohm Resistor, 5%, 1/4 Watt	
R10	1	4.7 Kohm Resistor, 5%, 1/4 Watt	
S1	1	SPDT Miniature Toggle Switch, Panel Mount	Note 8

Note 1 - Jameco part number 33195
Note 2 - Digi-Key part number LTC1063CN8-ND
Note 3 - Digi-Key part number NJM78L05A-ND
Note 4 - Digi-Key part number NJM79L05A-ND
Note 5 - Digi-Key part number ARFX1064-ND
Note 6 - Digi-Key part number 275-1014-ND
Note 7 - RadioShack part number 271-092
Note 8 - RadioShack part number 275-620

capacitor to filter out any unwanted noise.

In doing research, I often need small special instruments or circuit modules to try out concepts or make test measurements. This involves building up simple circuits such as amplifiers or filters to use with conventional instruments — circuits that are general enough to be used again. But providing power for such circuits becomes unwieldy if lab supplies are used and expensive if power supplies are included. My solution is an unregulated power supply having four output voltages: two positive and two negative. (Refer to "Modular Instrument System," June 2000 issue of *Nuts & Volts*.)

To connect this power supply to an instrument module, I use five pin DIN audio connectors with standardized pinouts so any instrument module can be quickly connected to power (Figure 2, Power Connector Pin Outs). Therefore, an instrument module only requires filter capacitors and voltage regulators for its power supply. After regulation, ±12 volts and ±5 volts are available. This power supply has multiple outputs, so several modular instruments can be used at once (Figure 3, Instrument Setup). Using short BNC cables, I can do a "lash up" of instrument modules to do an experiment.

Since only ±5 volts is required for this instrument, only two regulators are installed: A3 for the +5 volts and A4 for the -5 volts.

Building the Filter

As seen by the schematic (Figure 1), this circuit is simple and requires only a few connections. Working at low frequencies, the component layout is not critical, but lowest noise is achieved with a good ground plane. This circuit can be built on a blank copper circuit board or on a perf board prototyping board such as RadioShack's "General-Purpose IC PC Board" part number 275-150.

I chose the blank copper circuit board for my filter to gain the best noise performance (Figure 4, Instrument Interior). The manufacturer's data sheet recommends a good ground to achieve the lowest feed through noise level from the filter's clock. Although this method of construction is not very ecstatic, many electronic hobbyists don't realize how electrically sound this construction method is. If you want really quiet circuits, then use lots of ground plane.

Like most of my modular instruments, I use aluminum enclosures such as RadioShack's "Aluminum Project Enclosure" part number 270-238 and install the circuit board upside down on the inside of the box's top. Controls and connections go on the ends of the box with the power connector on the back end (Figure 5, Instrument Face).

No parts should be mounted on the bottom section (the part that forms the sides and goes "into" the top), thus avoiding connections which must be disconnected every time the instrument is taken apart. When a copper circuit board is used, it can be mounted with a single 4-40 screw and nut. Position the circuit board where you want to mount it, select a empty spot near the center of the board, then drill a 1/8 inch hole through both the box top and circuit board.

The controls and connectors — such as the input and output BNC connections — can be labeled with a home label machine. I use the silver colored tape with the outlined text mode which blends in well with the box's natural aluminum color. Since the bottom has no electrical connections, you can test the instrument with it removed, make any adjustments, then install the bottom using the four screws. Make sure the points of these screws do not contact any electrical part of the instrument as they make a great short to ground.

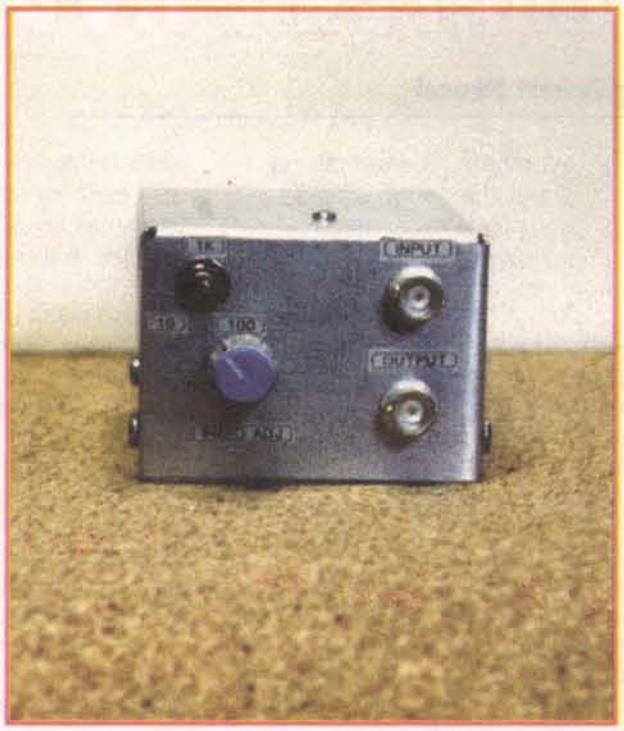

Figure 5. Instrument Face

Using the Filter

Other than setting the filter's cutoff frequency, there is little to using this instrument. The easiest way to set the frequency is to connect a function generator — set at the desired cutoff frequency — to the filter's input while monitoring its output with an oscilloscope or AC voltmeter.

There is no power switch on the instrument module, instead the power supply itself is turned on. Adjust the frequency range via switch S1 and the frequency via variable resistor R5 until the signal is at maximum voltage, then adjust R5 until the signal is one-half its original level. The filter's cutoff frequency is now set and the filter is ready to use.

Disconnect the filter's input and output and connect the filter into your test setup. This may be done with the instrument's power still on.

The input impedance of the filter is one megohm so there should be no loading of the signal source, but the output is NOT a 50 ohm source even though there is a 47 ohm resistor in series. The opamp for the buffer cannot drive such a low impedance so the output load should be at least one Kohm and preferably more.

Although the input buffer amplifier will clip waveforms greater than ±4 volts, it is advisable not to try and use this instrument with inputs that exceed this limit. An external resistive voltage divider should be used to reduce the input below the over voltage condition.

Excessive voltage for a long period may damage the input buffer amplifier so it's always advisable to check the input level before applying it to the filter. Better safe than sorry.

Your tunable filter is now ready for your next test setup. I have found mine to be a great addition to my lab and I'm sure you will find the same. Additionally, you will find the LTC1063 useful in your circuit designs. **NV**

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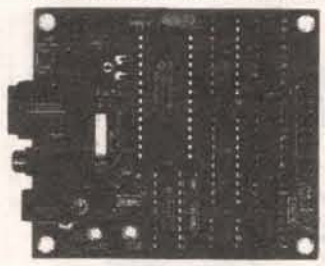

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